§25. Transition of Turbulence at the Onset of Internal Transport Barrier

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One of the problems in understanding the internal transport barrier is a difference in thetransport barrier formation of electrons and ions. Applying the statistical theory of turbuelnce where different collective modes with different scale lengths coexist [1], the problem of the ion transport barrier formation is investigated.

We study the nonlinear interplay between the semimicro mode (such as ITG mode) and micro mode (such as CDBM). In the following, the superscripts l and h denote the semi-micro and micro modes, respectively. The extended Fluctuation Dissipation Relation has been derived in terms of spectral intensities I^l and I^h as

$$\left(\frac{\sqrt{I^h}+\sqrt{I^h+4I^l}}{2}-D^l\right)I^l=\varepsilon\left(I^h\right)^{3/2} \quad (1)$$

$$I^h=\left(D^h\right)^2\frac{1}{\left(1+I_{eff}^{-1}I^l\right)^2}\left(1+\frac{\sqrt{I^l}}{\sqrt{I^h}+\sqrt{I^h+4I^l}}\right) \quad (2)$$

where $D^l=\dfrac{2}{2-C_0^l}\dfrac{1}{k_0^{l\,2}}\dfrac{\gamma_0^l}{1+\left(\omega_{E1}/\omega_{Ec}^l\right)^2}$ and

$D^h=\dfrac{2}{2-C_0^h}\dfrac{1}{1+\left(\omega_{E1}/\omega_{Ec}^h\right)^2}\dfrac{\gamma_0^h}{k_0^{h\,2}}$ denote the magnitudes of the driving power by the global inhomogeneity, and are the characteristic value of the diffusivity by the semi-micro mode and micro mode, respectively.

The smallness parameter $\varepsilon=\hat{C}_0^h\left(k_0^l/k_0^h\right)^2/\left(2-C_0^l\right)$ represents the coupling coefficient for the drive of the semi-micro mode by the nonlinear noise of micro mode, and

$I_{eff}\equiv\left(1+\left(\omega_{E1}/\omega_{Ec}^h\right)^2\right)\left(\omega_{Ec}^h\right)^2\left(k^l\right)^{-4}$.

Self-consistent solutions for Eqs.(1) and (2) can be multiple and show the hard bifurcation. The cusp catastrophe is shown in Fig.1, and the critical point of the cusp is given as $D^l=D^h=\sqrt{I_{eff}}$. A cusp type catastrophe is obtained. In the region of "micro", the semi-micro mode level is quenched and is very low. In the region of "semi-micro", the micro mode coexists but is suppressed.

The global radial electric field introduces new dynamical transitions in the presence of nonlinear interactions between fluctuations of different scale length. When the nonlinear interactions between different fluctuations are neglected, the inhomogeneous radial electric field suppresses the fluctuations. In the case of $\omega_{Ec}^l\le\omega_{Ec}^h$, Fig.1 shows the trajectory of the driving parameters D^l and D^h as the global electric field shear increases. ω_{E1} changes from $\omega_{E1}/\omega_{Ec}^l=0$ to $\omega_{E1}/\omega_{Ec}^l=2$. States A and B (in the absence of the electric field shear) is chosen in the branch where semi-micro fluctuations dominates. A hard transition takes place at C and the back-transition at C'. When the electric field shear ω_{E1} is increased, the semi-micro mode starts to be suppressed by the electric field shear. The micro mode, however, starts to be enhanced, because the suppression by the semi-micro mode is reduced.

The problem of slow electron-ITB formation could be solved by considering the transition of the semi-micro and micro turbulence due to their nonlinear interactions. At the transition, the semi-micro mode is almost completely quenched, but the micro mode can jump up to a large amplitude. In the behaviour of the ion thermal conductivity, the transition occurs at a critical value of the gradient of the global $E\times B$ velocity. Above this threshold value, the semi-micro mode is quenched and the ion thermal conductivity decreases strongly. The micro mode fluctuation is enhanced, so that the total electron thermal transport does not decrease much but starts gradual reduction.

Reference

1) Itoh S-I and Itoh K Plasma Phys. Contr. Fusion 43 (2001)